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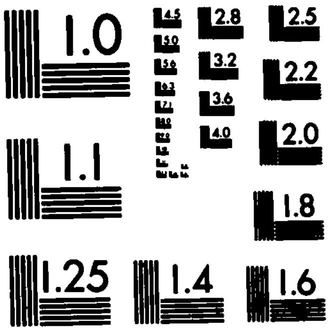
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Special Report 82-24

November 1982

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Energy conservation at the West Dover, Vermont, water pollution control facility

C.J. Martel, B.C. Sargent and W. Bronson

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An energy audit was conducted at the West Dover, Vermont, water pollution control facility. The audit revealed that aeration, not pumping to the land treatment site, was the largest energy consumer. As a result of the audit, five Energy Conservation Opportunities (EOC) were evaluated. Three of the ECOs were recommended for implementation; these could result in annual savings of more than $6000. The remaining two ECOs were not recommended because of a large capital investment required and a long payback period.

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PREFACE

This report was prepared by C. James Martel, Environmental Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory; Benson C. Sargent, Vermont Department of Water Resources and Environmental Engineering; and Wallace Bronson, Superintendent, North Branch Fire District No. 1 Water Pollution Control Facility. Funding for this study was provided by DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Task C, Cold Regions Base Support: Maintenance and Operations, Work Unit 001, Operations and Maintenance of Cold Regions Sanitary Engineering Facilities.

Sherwood Reed and Peter Smallidge of CRREL technically reviewed the manuscript of this report.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Multiply	By	To obtain
acre	0.40469	hectare
Btu	1055.056	joule
foot	0.3048	meter
horsepower	0.7457	kilowatt
inch	25.4	millimeter
pound	0.4536	kilogram
million gallons/day	3785	$meter^3/day$
gallon	0.003785	$meter^3$

ENERGY CONSERVATION AT THE WEST DOVER, VERMONT, WATER POLLUTION CONTROL FACILITY

C.J. Martel, B.C. Sargent and W. Bronson

INTRODUCTION

Background

One of the goals of the Department of Defense Energy Management Plan is to achieve a reduction in energy consumption at facilities of 20% by 1985 and 40% by the year 2000 (U.S. Army 1981). To accomplish this goal, the Army has decided that the short-term focus of energy research and development should be on conservation. Reducing energy consumption by conservation will require careful management of all base utilities, including wastewater treatment plants. Treatment plants have always consumed large amounts of energy for pumping, aeration and sludge processing. Even more energy is needed for plants located in cold regions because the process equipment is often installed within a heated enclosure to facilitate maintenance and to prevent freezeups.

To develop the expertise and techniques needed to identify potential energy conservation measures at wastewater treatment plants, a case study was conducted at the West Dover, Vermont, water pollution control facility. This facility was selected because it is about the same size as many military treatment plants and it allows evaluation of a wide variety of processes (primary, secondary and tertiary).

Objectives

The primary objectives of this study were to

1. Conduct an energy audit of the West Dover facility.
2. Identify Energy Conservation Opportunities (ECOs) as a result of the audit.
3. Evaluate the ECOs in terms of potential cost savings and payback period.

Description of facility

Officially called the North Branch Fire District No. 1 Water Pollution Control Facility, the West Dover plant was constructed in 1975. The average daily design flow of the facility is 0.55 million gallon per day (mgd). Currently, the average flow is only 0.075 mgd in the summer and 0.15 mgd in the winter. The higher winter flow is due to a local ski resort. The total annual flow during 1980 was 29.0 million gallons.

The wastewater treatment processes at the plant consist of two oxidation ditches (only one of which is currently operating), a polishing pond and a holding pond (see Fig. 1). The effluent is sprayed on a hilly 34 acre forested site with slopes ranging from 8 to 25%. Runoff from the site

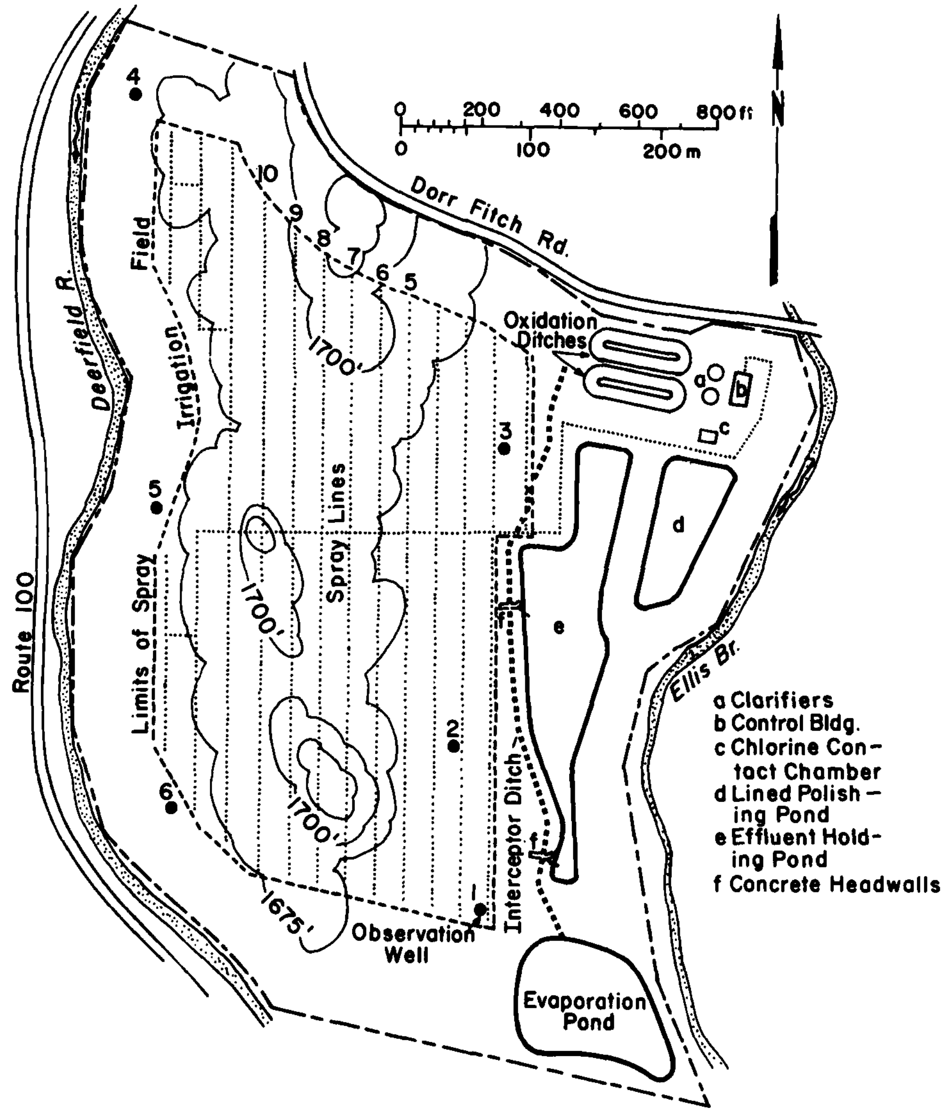

Figure 1. Overview of West Dover facility.

is channeled to a percolation-evaporation pond. Sludge is stabilized in an aerobic digester, conditioned with a polymer and dewatered with a dual-cell gravity rotating screen device. This sludge is then used as a soil amendment on cornfields and pastures. A more detailed description of this facility and its performance can be found in a report by Cassell et al. (1980).

The total operation and maintenance cost of this facility during 1980 was $54,467.34. Energy consumption accounted for 25% of this amount. Electrical energy costs accounted for 80% of the energy bill and the remaining 20% was for heating oil.

ENERGY AUDIT

Historical use

The first step of any energy audit is to obtain records of past energy use. Records of past electric consumption and cost were provided by the Green Mountain Power Corporation of Burlington, Vermont (see Appendix A). Records of heating oil consumption were obtained from billing statements provided by the operator. Tables 1 and 2 show the annual electric and oil consumption and costs for the years 1978, 1979 and 1980.

The electric consumption data shown in Table 1 indicate that electric use has steadily decreased over the 3-year period (1978-1980). According to the operator this reduction was obtained through a number of energy conservation measures, such as using only one spray pump at a time and carefully monitoring each piece of equipment to ensure peak operating efficiency. During 1980, the total electric use was 356,240 kWh at a cost of $11,154.88, which is equivalent to $0.031/kWh. This unit cost was used in all subsequent calculations of cost savings as a result of energy conservation measures.

Table 1 also shows that demand charges accounted for 35 to 45% of the total electric costs. A demand charge is a special rate charged for peak loads over a specified time interval, usually 15 minutes. The power company applies a high demand charge when many pieces of equipment are operated simultaneously. Therefore, the best way to reduce the demand charge is by spacing out various operations so that periods of peak power demand are kept at minimum levels. At the West Dover facility the highest demand charges occurred during the winter months when the spray pumps were in operation.

Table 1. Annual electric consumption and costs at the West Dover facility.

Year	Electric use (kWh)	Demand charge ($)	Energy* costs ($)	Total costs ($)
1978	432,640	--	--	15,293.29
1979	419,040	4220.00	8016.23	12,236.23
1980	356,240	5000.00	6154,88	11,154.88

* Includes customer charge of $120/year

Table 2. Annual oil consumption and costs at the West Dover facility.

Year	Number of gallons	Total cost ($)
1978	4281	1948
1979	4969	3051
1980	3150	2763
Average	4133	2587

The average fuel oil consumption over the 3-year period was 4133 gal. (see Table 2). Most of this oil was used for space heating in the administration and laboratory areas of the control building. A small amount was used by emergency electrical generators at the plant and pump stations during regular start-up checks. During 1980 the average cost of the fuel oil was $0.88/gal.

Energy use by major equipment

The next step taken in the audit was to estimate the energy used by each piece of equipment. A survey was taken of all equipment along with the motor nameplate data. As shown in Table 3 this survey identified 13 items of equipment used at the facility. Of this number, eight were judged to be major pieces of equipment based on size and frequency of use. These include the brush aerators, spray pumps, digester blower, process water pumps, sludge return pumps, holding and transfer pumps, sludge scraper in the clarifier, and a comminutor.

Table 3. Motor nameplate data from electrical equipment at West Dover facility.

Equipment	hp	V	hz	A	rpm	Service factor	Manufacturer	Model number	Serial number
Brush aerators (2)*	20	230/460	60	50/25	1750	1.15	Lincoln A.C.	Linguard	1473553
Aerobic digester blower	15	230/460	60	40/20	1750	1.15	Lincoln A.C.	Linguard	1465229
Process water pumps (2)	10	230/460	60	40/20	1675	--	Marathon	AJ284TST DR76-32AAW	---
Sludge recirculation pumps (3)	20	230/460	60	25.7/15.8	1150	1.15	General Elec.	SK32AN9189	---
Spray pumps (3)	50	230/460	60	120/60	3530	1.15	Reliance	324 Type P	1MA465395-G4-J2
Transfer pumps (2)	10	230/460	60	27/13.5	1755	1.15	Reliance	Type P	P21G2701C-E4
Sludge scraper (2)	0.75	230/460	60	3.44/1.72	1725	--	Reliance	Type P	P56G133 7N-GW
Large plunger pump	10	230/460	60	28/14	1155	1.15	U.S. Elect.	---	---
Small plunger pump	1.5	230/460	60	6.2/3.1	1710	--	U.S. Elect.	---	---
Portable air compressor	1.25	230/460	60	5/2.5	--	--	U.S. Elect.	---	F4433-01-316
Comminutor	0.75	230/460	60	2.4/1.2	1740	1.0	General Elec.	---	5K143PK 2166
Dewatering unit	0.25	230/115	60	5.2/2.6	1725	--	General Elec.	---	5K3C7KG 307
Lightning mixer	0.25	115	60	4.4	1725	--	Lightning	---	753220

* Number of pieces.

The annual electric consumption rates for each major piece of equipment are shown in Table 4. These rates were calculated according to the relationship

$$K = \frac{1.732 \ EIH \ (PF)}{1000} \qquad (1)$$

where K = annual electric consumption (kWh)

E = average voltage (V)

I = average measured current (A)

H = average annual operating time (hr)

PF = power factor.

At the West Dover facility, the voltage rating for all major pieces of equipment is 460 V. The amperage was measured with a portable ammeter during normal operation. The annual operating time was obtained from plant records or estimated by the operator. The power factor was measured at 0.92 (see Appendix B).

After a summation of the electric consumption of each major piece of equipment, the total electric power consumed is seen to be 493,564 kWh/yr.

Table 4. Estimated annual electric consumption by equipment at West Dover facility.

Equipment	Approx. operating schedule	Estimated annual operating time (hrs)	Measured current (A)	Voltage (V)	Annual electric consumption (kWh)
Brush aerators	Both continuously	8760	15	460	192,628
Spray pumps	One at a time, as deemed necessary by operator	2250	55	460	90,707
Digester blower	Continuous	8760	18	460	115,577
Process water pumps	Alternating continuous operation	8760	8	460	51,367
Sludge return pumps	One pump at a time, 410 min./day	2494	8	460	14,624
Transfer pumps	One pump at a time, 600 hr/yr	600	10	460	4398
Sludge scraper	Continuous	8760	2	460	12,842
Comminutor	Continuous	8760	1	460	6421
Lighting and misc. equipment	---	--	--	--	5000
				Total	493,564

This estimate is significantly greater than the actual power used during any of the 3 previous years (see Table 1). The reason for the discrepancy appears to be that the actual operating time of some pieces of equipment was less than estimated. Downtime for maintenance and repair was not considered in the operating time estimates. Therefore, the annual electric consumption shown in Table 4 would only occur if everything operated without a breakdown. Although this is unlikely, it is not unreasonable to assume that a particular piece of equipment will operate for a year or more without downtime. As a result, the electric consumption figures shown in Table 4 for each piece of equipment were used for evaluating the impact of energy conservation measures.

Energy use by function

To identify the most lucrative areas for energy conservation, various equipment operations were combined under broader functions of the treatment plant. At the West Dover facility these functions are aeration, land treatment, in-plant processes and heating. As shown in Table 5, the largest energy-using function was aeration of the oxidation ditch and the aerobic digester (46%). Heating was the second highest energy consumer (27%). Although it was originally suspected that land treatment pumping

Table 5. Calculated annual energy consumption by function at the West Dover facility.

Function	Equipment	Annual energy* consumption (Btu x 10^6)	Percent of total
Aeration	Rotors Digester blower	972	46
Land treatment	Spray pump Transfer pump	300	14
In-plant processes	Process water pump Sludge return pump Sludge scraper Comminutor	266	12
Heating	Oil furnace	579	27
Miscellaneous	Lighting, misc. equipment	17	1
	Totals	2134	100

* The conversions of kWh and gallons of fuel oil to Btu were based on 3413 Btu/kWh and 140,000 Btu/gal. of fuel oil.

was going to be the largest energy consumer, the analysis shown in Table 5 indicates that it represents only 14% of the total energy used by the facility. In-plant processes, which include process water pumping, sludge return pumping, the sludge scraper in the clarifier and the comminutor, accounted for 12%. The remaining 1% was consumed by miscellaneous equipment and lighting.

ENERGY CONSERVATION OPPORTUNITIES

After completion of the energy audit, it was possible to identify potential Energy Conservation Opportunities (ECOs) and evaluate their cost effectiveness. At the West Dover facility, 15 ECOs were initially identified; five of these were selected for further evaluation. The following is a discussion of each of these five ECOs along with an evaluation of potential cost savings and payback period. Because of treatment process modifications, implementation of these ECOs will require approval from the Vermont Department of Water Resources and Environmental Engineering and, in

some cases, the Vermont Department of Health. However, all of the proposed ECOs are consistent with the U.S. Environmental Protection Agency (EPA) policy and design guidance in the Process Design Manual for Land Treatment of Municipal Wastewater (EPA 1981).

Discontinue chlorination of oxidation ditch effluent

Chlorination of the oxidation ditch effluent may be unnecessary because it never comes in contact with streams or land areas where public access is allowed. After disinfection, the oxidation ditch effluent enters a polishing pond from which it is sprayed on the land treatment site. Both of these areas are within the fenced-off boundaries of the facility. Eliminating chlorination would save energy by eliminating the need for most of the process water pumping.

Potential energy savings:	51,367 kWh/yr
Potential cost savings:	51,367 kWh/yr x \$0.031/kWh = \$1592/yr
Estimated retrofit costs:	None
Estimated payback period:	Immediate

Discontinue aerobic digestion

Instead of aerobically digesting the waste activated sludge, it may be possible to mix it directly with pond effluent and spray it onto the land treatment site. Odors should not be a problem because the sludge will be diluted and dispersed over a wide area. Public health would be protected because access to the spray site is controlled. Runoff water quality is not expected to deteriorate because the sludge should quickly settle out and remain on the soil surface. However, large diameter nozzles would be needed to spray sludge solids and the waste sludge line from the clarifier would have to be tied in with the spray pump header.

Potential energy savings:	115,577 kWh/yr	
Potential cost savings:	115,577 kWh/yr x \$0.031/kWh = \$3583/yr	
Estimated retrofit cost:	100 nozzles at \$8 each:	\$ 800
	Repiping:	\$3000
	Total	\$3800

Estimated payback period: $\frac{\$3800}{\$3583/yr} = 1.1$ years

Discharge contents of holding pond into percolation-evaporation pond

One of the major reasons for the high pumping costs is that much of the water sprayed onto the site seeps back into the holding pond and must be repumped. Seepage points can be seen along the western side of the pond. These observations were confirmed by meter readings which showed that the volume of effluent sprayed was nearly twice the volume of wastewater received. To reduce seepage the holding pond could be held at full capacity during the spring runoff period when most of the seepage occurs. If the pond overflows during this period it could be discharged into the percolation-evaporation pond through an existing overflow pipe which was installed for this purpose. The potential pollution caused by this practice is expected to be minimal because the wastewater in the holding pond will have been diluted by the seepage. As a precaution against further pollution, no new wastewater would be allowed into the holding pond until it had been emptied. All wastewater received during the spring runoff period would be sprayed directly onto the land treatment site from the polishing pond.

In the summer, when groundwater levels have lowered and most of the seepage has stopped, the contents of the holding pond would then be released into the percolation-evaporation pond. Again, the quality of this water is expected to be excellent because of the mixing with groundwater and precipitation. To discharge the contents of the holding pond, a valved drain pipe would have to be installed.

Potential energy saving: By maintaining a full holding pond during spring runoff and discharging the contents during the summer, it is estimated that pumping will be reduced by 30%. Based on this conservative assumption, the potential energy saving is:

$$90{,}707 \text{ kWh/yr} \times 0.3 = 27{,}212 \text{ kWh/yr}$$

Potential cost savings: 27,212 kWh/yr x \$0.031/kWh = \$844/yr

Estimated retrofit cost: To drain the holding pond a 150-ft-long, 10-in.-diameter pipe would be needed at the south end. The average depth of cover is estimated to be 15 ft. According to updated unit cost figures from Reed et al. (1979), the total cost of this pipeline would be approximately \$6000.

$$\text{Estimated payback period: } \frac{\$6000}{\$844/\text{yr}} = 7.1 \text{ years}$$

Replace oxidation ditches with facultative ponds

The energy audit showed that aeration of the oxidation ditches and aerobic digester consumed the greatest portion of the energy used at the West Dover facility (see Table 5). The need for aeration could be eliminated by replacing the oxidation ditches with facultative ponds. Also, this would eliminate the need for aerobic digestion, in-plant process water, sludge return pumps, transfer pumps and the sludge scraper in the clarifier. Based on an average influent BOD (Biochemical Oxygen Demand) of 1170 lb/day (from original facility plan) and a BOD loading of 60 lb/acre, the area needed for the facultative ponds would be 20 acres. The existing 5-acre holding pond could be converted to a facultative pond by lining the bottom. The additional 15 acres of ponds would have to be constructed in the gravelly area south of the plant in the town of Wilmington. With the assumption that this could be done, the potential energy savings and retrofit costs are as follows.

Potential energy savings (kWh):

Aerators	192,628
Blower	115,577
Process water	51,367
Sludge return pumps	14,624
Transfer pumps	4,398
Sludge scraper	12,842
Total	391,436

Potential cost savings: 391,436 kWh/yr x $0.031/kWh = $12,135/yr

Estimated retrofit costs: The estimated costs of building the facultative ponds were calculated from Reed et al. (1979) using a sewer construction cost index of 401.2 (first quarter 1981).

Holding pond liner (Reed et al. 1979, p. 59):

$40,000 (for 16 million gal.) x 1.21 (PVC adj. factor)* x 401.2/194.2 = $99,990

Fifteen acre facultative pond (Reed et al. 1979, p. 46):

Construction cost (use 0.4 mgd):	$43,000 x 401.2/177.5 =	$97,192
PVC liner (for 24 million gal.):	$65,000 x 401.2/194.2 =	$134,284
Land cost (15 acres at $2000/acre):		$30,000
	Total	$361,466

* Adjustment factor for using PVC liner.

Estimated payback period: $\frac{\$361,466}{\$12,135/yr}$ = 30 years

Replace spray irrigation with rapid infiltration

According to the Soil Conservation Service (SCS) soils map, the land just south of the plant has moderately well-drained soils. This is confirmed by the fact that a part of this site was once used as a gravel pit. Also, the percolation-evaporation pond is in this area. Therefore, there is good reason to believe that suitable soils exist in this area for a series of rapid infiltration basins. By use of a conservative application rate of 20 in./wk (EPA 1981) and a design flow of 0.55 mgd, the total area needed for rapid infiltration is 20 acres.

The SCS map also indicates that the depth to seasonal high water table is only 1.5 to 2.5 ft. If hydrogeologic studies confirm this, rapid infiltration could not be used during springtime. However, the existing polishing and holding ponds might serve as storage ponds during this time or the spray area could be reactivated.

If a rapid infiltation system was constructed, the energy consumed by the brush aerators, spray pumps, process water pumps and transfer pumps could be eliminated. The existing secondary clarifiers could be converted to primary clarifiers. The primary sludge could be stabilized in the present aerobic digester.

Potential energy savings (kWh):

Aerators	192,628
Process water	51,367
Spray pumps	90,707
Transfer pumps	4,398
Total	339,100

Potential cost savings: 339,100 kWh/yr x \$0.031/kWh = \$10,512/yr

Estimated retrofit costs: The estimated costs of building the rapid infiltration basins were calculated from Reed et al. (1979) using a sewer construction cost index of 401.2 (first quarter 1981).

Construction cost (Reed et al. 1979, p. 75):	\$50,000 (for 10 acres) x 401.2/194.2 =	\$103,295
Repiping (Reed et al. 1979, p. 51 for 10-in. pipe, 5 ft of cover):	(\$10/linear ft) x 200 ft x 401.2/194.2 =	\$ 4,132
Land costs (20 acres at \$2000/acre):		\$ 40,000
	Total	\$147,427

Estimated payback period: $\frac{\$147,427}{\$10,512/yr}$ = 14 years

SUMMARY AND RECOMMENDATIONS

A summary of ECOs for the West Dover facility is shown in Table 6. The first two ECOs represent a combined annual savings of $5175/yr which is currently almost 50% of the total electric cost. Also, the payback period on these ECOs is relatively short. As a result, it is recommended that these ECOs be implemented as soon as possible. Discussions should be initiated with the Vermont Department of Health and the Vermont Department of Water Resources and Environmental Engineering to seek approval.

Because of the relatively low annual savings ($844) and the longer payback period (7.1 years) the justification for adoption of ECO 3 is not as strong for as ECOs 1 and 2. However, the estimated retrofit cost of implementing ECO 3 is only $6000, which is affordable even for a small town like West Dover, Vermont. Therefore, adoption of ECO 3 is recommended.

The remaining ECOs (4 and 5) required extensive changes to the facility that would involve a substantial capital investment. These ECOs have greater potential energy savings but a long payback period. As a result, adoption of ECOs 4 and 5 is not recommended at this time. However, they should be reconsidered if the facility requires expansion in the future.

It should be noted that other cost savings would be gained by adopting the ECOs recommended in this study. For example, adoption of ECO 1, which

Table 6. Summary of ECOs for the West Dover facility.

No.	Description	Cost savings ($)	Simple payback (years)
1	Discontinue chlorination of oxidation ditch effluent	1,592	Immediate
2	Discontinue aerobic digestion	3,583	1.1
3	Discharge contents of holding pond into the percolation-evaporation pond	844	7.1
4	Replace oxidation ditches with facultative ponds	12,135	30.0
5	Replace spray irrigation with rapid infiltration	10,512	14.0

eliminates chlorination, would save approximately $2250/yr in chemical costs. Labor costs would also be reduced because the facility would be less complex to operate. Another factor not considered is the reduced wear and tear on equipment as a result of a simplified treatment scheme. These additional savings should be included in a more detailed evaluation of the proposed ECOs prior to implementation.

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APPENDIX A: MONTHLY POWER CONSUMPTION AND COST AT THE WEST DOVER, VERMONT, WATER POLLUTION CONTROL FACILITY

Month	Energy consumption (kWh)	Energy cost ($)	Demand cost (kWh/$)	Total* cost ($)
January 1978	40,480	1419.63	124/no cost	1429.63
February	39,680	1391.58	152/no cost	1401.58
March	44,880	1573.94	136/no cost	1583.94
April	49,040	1719.83	120/no cost	1729.83
May	41,440	1453.30	128/no cost	1463.30
June	31,440	1102.60	128/no cost	1112.60
July	27,360	959.52	84/no cost	969.52
August	30,080	1054.91	92/no cost	1064.91
September	32,880	1153.10	92/no cost	1163.10
October	35,120	1231.66	92/no cost	1241.66
November	30,560	1071.74	92/no cost	1081.74
December	29,680	1040.88	92/no cost	1050.88
January 1979	33,040	1158.71	132/no cost	1168.71
February	33,120	1161.52	128/no cost	1171.52
March	43,120	1512.22	104/no cost	1522.22
April	40,880	513.86	108/540	1063.86
May	43,120	534.30	92/460	1004.30
June	31,760	400.66	88/440	850.66
July	37,360	464,44	84/420	894.44
August	31,840	401.54	88/440	851.59
September	39,840	497.53	96/480	987.53
October	38,560	482.63	96/480	972.63
November	30,720	391.37	96/480	881.37
December	29,520	377.40	96/480	867.40
January 1980	39,200	492.90	104/520	1022.90
February	32,080	407.20	96/480	897.20
March	29,360	354.54	96/480	865.54
April	30,880	389.01	84/420	819.01
May	35,680	442.07	76/380	832.07
June	29,680	372.23	76/380	762.23
July	26,880	598.76	76/380	988.76
August	26,960	600.46	76/380	990.46
September	28,240	627.10	76/380	1017.70
October	25,920	578.33	76/380	968.23
November	27,680	618.60	84/420	1048.60
December	23,680	532.08	80/400	942.08

* $10.00 customer charge included.

APPENDIX B. MEASUREMENT OF THE POWER FACTOR AT THE WEST DOVER, VERMONT, WATER POLLUTION CONTROL FACILITY

The power factor (PF) is the relationship between current and voltage in alternating current systems. Under ideal conditions, both current and voltage are in phase and the power factor is 1.0. However, when motors are connected to the system, the current and voltage become out of phase and the power factor becomes less than 1.0. A low power factor causes a demand for a higher current flow to make up for the phase imbalance. This higher current flow is not registered on the electric meter and so the power company is actually providing more power than the customer is paying for. This is why most power companies require large users to keep their power factor as high as possible (typically between 0.8 to 0.9). The Green Mountain Power Corporation requires that each customer maintain a power factor of 0.85 or higher under ordinary load conditions. The customer is charged a penalty if the power factor goes below 0.85.

Except for large plants, the power factor is not monitored by the power company. However, the power factor can be estimated by measuring the apparent power and the actual power used over a given time interval. The apparent power is the power used by the facility based on measured current and voltage. For a three phase service, the apparent power consumed can be calculated as follows:

$$KVA = \frac{1.732\ EI}{1000} \qquad \text{B1}$$

where KVA = apparent power consumed (kWh)

E = average voltage over given time interval

I = average amperage over given time interval.

The actual power (KW) used by the facility is measured by the kilowatt-hour meter. The ratio between actual power (KW) and apparent power (KVA) is the power factor (PF), and can be expressed as:

$$PF = \frac{KW}{KVA} \ . \qquad \text{B2}$$

On 13 January 1982, voltage and amperage used by the plant between the hours of 10:30 AM to 2:00 PM (see Table B1) were recorded. During this period all major equipment including a spray pump and a blower were running. The voltage and amperage were measured at the control panel.

From Table B1, the kilowatt-hour meter recorded a 3.1 unit change over a 3-hour period. To calculate the number of kilowatt-hours used during this period, the unit change was multiplied by a meter constant, which in this case was 80. Therefore the amount of kilowatt-hours used during the 3-hour period was 248 kWh (3.1 x 80), and actual power (kW) used per hour was 82.7 kW.

The average amperage (A) and voltage (V) measured during the 3-hour period (H) were 108 and 480 respectively. From equation B1 the apparent power (KVA) was calculated to be 89.7 kW (1.732 x 480 x 108/1000).

With knowledge of the actual power (KW) and the apparent power (KVA), the power factor can be calculated using equation B2. In this case

$$PF = \frac{82.7}{89.7} = 0.92.$$

Table B1. Meter readings for power factor calculation.

Elapsed time (hr)	Meter reading (kWh)	Amperage (3 phase)	Voltage (3 phase)
0	8817.6	120/120/110	480/480/490
0.25	--	120/110/100	480/480/490
0.50	--	120/115/105	475/480/490
0.75	--	110/105/100	480/480/490
1.0	8818.8	110/100/100	475/480/490
2.0	8819.8	110/105/105	480/480/490
2.5	8820.1	110/105/100	480/480/490
3.0	8820.7	110/105/100	480/480/490

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